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Critical Reflections on Technology to Support Physical Activity Among Older Adults: An Exploration of Leading HCI Venues ~~Critical Reflections on Technology to Support Physical Activity Among Older Adults: An Exploration of Major HCI Venues~~

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Critical Reflections on Technology to Support Physical Activity Among Older Adults: An Exploration of Leading HCI Venues ~~Critical Reflections on Technology to Support Physical Activity Among Older Adults~~

Contemporary policy on ageing overwhelmingly focuses on active ageing and achieving a sustainable increase in disability-free years, leading to an agenda that promotes interventions which often focus on deficits of older persons with little consideration of their perspectives on physical activity. As the integration of technology to support physical activity routines becomes more common, this trend also becomes relevant to the Human-Computer Interaction (HCI) research community.

In this paper, we present findings from a structured search~~systematic review~~ of technical systems addressing physical activity among older adults that were published at the most cited~~leading~~ HCI venues. Drawing from Thematic Analysis, we explore how the model of active ageing informs existing research, and how it is operationalized in technology design. We find that the deficit-focused perspective on ageing is reflected in many technology solutions published at the most visible HCI venues, and discuss shortcomings and strengths of present research to help guide discourse and future work in HCI.

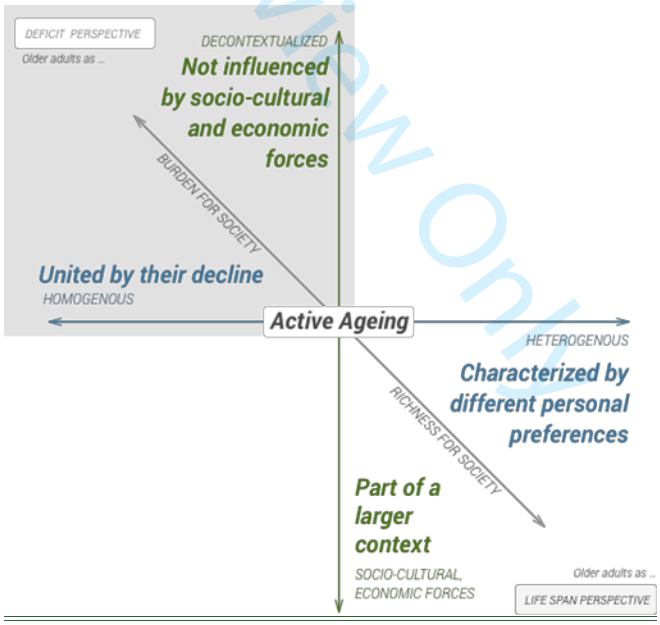
Keywords: Older adults; physical activity; wearables; movement-based games; rehabilitation; review

1. Introduction

In 2050, there will be more than 2 billion people aged 60 and older, with a significant ~~share~~proportion of them ~~people~~ older than 80 years (WHO, 2019). ~~There are over 10 million older people in the UK, a figure estimated to rise further to 16.4 million by 2033.~~ One driver of this trend is the lengthening of the average lifespan, enabled through medical progress, improved access to health care and advances in socio-economic conditions. Despite this already heightened life expectancy, a further

increase in the period of healthy, disability-free and independent living remains of significant concern to policy makers and healthcare providers. To this end, increased physical activity (PA) is a common ingredient to promote 'successful' or 'active' ageing (Katz & Calasanti, 2015; Martinson & Berridge, 2015; Spirduso et al., 2005). Consequently, ~~PA~~physical activity has become a key policy response to the perceived challenges presented by an ageing population. Generally, a strong economic case accompanies the policy aspiration. The need for active ageing is often justified by highlighting societal challenges, including the financial pressures placed upon pension and healthcare systems by an ageing, deficit-ridden population requiring long-term care (NICE, 2015).

Figure 1. Illustration of the different possible perspectives and dimensions of the 'Active Ageing'- model.



A significant and growing number of researchers in Sport Science, have focused on the association between active lifestyles and health in later life. Physical activity during later life has demonstrated benefits, both for physiological and psychological well-being, and there is growing scientific consensus that physical activity has social

benefits for older adults as well (e.g. Bangsbo et al., 2019). However, this focus on collecting evidence for the 'right' amount, intensity and duration of physical activity for older adults' (e.g. Giroir & Wright, 2018) has led to an interventionist culture: physiological, medical and cognitive-psychological interventions are employed to promote physical activity to 'at risk' populations such as older adults (e.g. Chase, Phillips, & Brown, 2016), and rarely consider other relevant factors such as the enjoyment of ~~PA~~physical activity (e.g., Phoenix & Orr, 2014) or the socio-cultural context. Such interventions may result in prescriptive, standardised solutions and have been challenged by critical sports science (Evans & Crust, 2015; Tulle, 2008).

Deficit-focused approaches toward active ageing conceptualise older adults as problematic; they fail to consider individuality, and neglect contextualising features such as the social determinants of health (Popay et al., 2010; Gard et al., 2016; Katz & Calasanti 2015). When designing technology to motivate physical activity ~~PA~~ among older adults, this deficit-ridden perspective on ageing may result in systems that reduce the user to a PA-related need, ability or capacity without taking into account other personal needs and preferences. As a result, there is a risk that technology interventions are effective at a functional level, but simultaneously ineffective when considering personal and emotional aspects.

More recently, Human-Computer Interaction (HCI) has entered dialogue around views on older adults and technology design. Papers by Cozza et al. (2017) and Vines et al. (2015) review ubiquitous computing technologies for older adults and the discourse on technology for older adults respectively, and outline the need for a more positive narrative to drive research and technology design in this area. Inspired by their work, we similarly aim to develop a more detailed understanding of how policy affects research processes and system design within the HCI community, and contribute to the

ongoing, critical discourses on ageing. In particular, in this review we focus on technology in the context of physical activity for older adults. We present findings from a ~~systematic review~~structured search of technical systems presented at leading international venues in HCI, and analyse what model of active ageing informs existing research published at main venues. We leverage the lenses of critical sports science to review existing systems, and examine shortcomings along with strengths to help guide future work in HCI. Moving beyond critical analysis, this paper also outlines challenges and opportunities be addressed, in order to create technology that offers room for the lived experiences of older adults, and empowers them to maintain ownership of their embodied experiences of physical activity~~PA~~.

2. Background

In response to concerns over increasing costs of healthcare for older adults, there has been a growing focus on the benefits of active lifestyles during old age, in both the natural sciences and in social sciences. Here, we discuss perspectives on physical activity ~~PA~~ in late life, we present views from sport science, and we summarise research efforts in HCI.

2.1 Reflections on the Discourse of ~~PA~~ and Ageing

Several competing discourses exist on the need for older adults to adopt and maintain active lifestyles. Many studies fall within the narrative of 'treating' age-related decline. For example, studies in the natural sciences emphasise the link between sedentary behaviours and risk of ill health amongst older adults (Gard et al., 2016; Tulle, 2008a). There is overwhelming evidence to suggest that the adoption and maintenance of active lifestyles is beneficial for older adults (Bangsbo et al., 2019; Chodzko-Zajko et al., 2009; Nelson et al., 2007; Taylor et al., 2004). Such work tends to promote physical

activity ~~PA~~ as a means for attenuating physical and psychological decline (amongst other problems) and health risk factors associated with old age (Nelson et al., 2007). In contrast, other studies place emphasis on active engagement and the presentation of later life as a time of leisure, freedom, pleasure, activity, challenge and growth (Gard et al., 2016; Katz & Calasanti, 2015; Phoenix & Orr, 2014; Tulle & Phoenix, 2015). These studies put forward the concept of 'active ageing', often interchangeably used with terms such as 'successful,' or 'healthy' ageing, to promote a more positive, anti-decline narrative of old age (Rowe & Kahn, 1997). More specifically, the 'active ageing' approach maintains that increased and long-term 'participation' in social, economic, cultural, spiritual and civic issues are beneficial for older adults (Mendes, 2013). However, similar to studies that emphasize the link between inactive lifestyles and ill health, the active-ageing concept tends to be oriented towards individual behaviour change and the provision of opportunities to become more active. As a result, such studies can be less effective in addressing the root causes of inequality, or in empowering those less able or willing to take such opportunities (Katz & Calasanti, 2015). This shortfall can actually exacerbate health inequalities, as well as stigmatize the inactive or unhealthy older adults (Martinson & Berridge, 2015, Gard & Dionigi 2016).

2.2 Promoting Physical Activity in Late Life: Views from Sport Science

The majority of interventions from a sports-scientific perspective that are designed to promote physical activity ~~PA~~ amongst older populations can be situated within the aforementioned narrative of 'treating' age-related decline ~~as well~~. The need for interventions is often couched in terms of prevention of illness, treating existing health problems or age/related diseases, or reducing healthcare expenditure. Information, education and communication-based interventions (or EICs), grounded in physiological

and behaviour change approaches, are therefore common in promoting physical activity ~~PA~~ (Bauman et al., 2016; Nutbeam, 2008; Williams & Gibson, 2017). Often, such programmes aim to encourage individuals to adopt healthy lifestyles via direct, expert-led interventions which a focus on educating participants about the beneficial effects of regular physical activity~~PA~~, the use of 'motivational methods,' such as physical activity ~~PA~~ consultations or prompts via mobile telephone (Bravata et al., 2007; Chen, 2005; De Cocker et al., 2008; Fitzsimons et al., 2008; King et al., 2013), and the provision of additional services and opportunities to be active in predominantly 'age-appropriate' forms of physical activity~~PA~~, such as walking (Ogilvie et al., 2007) and swimming (Evans & Sleap, 2013). These activities can be empowering for some groups of older adults, particularly those with the resources and means to maximise new and existing opportunities to engage and remain active (Gard & Dionigi, 2016; Gard et al., 2016; Phoenix & Sparkes, 2009).

On the other hand, there are problems with these methods and viewpoints, and many interventions have limited long-term impact. Many sport and physical activity ~~PA~~ interventions are short-term and are rarely evaluated in the long term. Overall, there seems to be a tendency towards 'initiativitis', or short-termism driven by competitive tendering, in sports and physical activity ~~PA~~ provision (Coalter, 2005). Moreover, the predominance of positivist scientific paradigms in many sports interventions means that they can exhibit a reductionist tendency, focusing on direct measurable physiological and cognitive-psychological effects, neglecting cultural and social inequalities that can produce and reproduce health inequalities (Williams & Gibson, 2017). A similar accusation of excessive focus on individual choice has been levelled at the 'successful' or 'active ageing' paradigm more widely, challenging mainstream perspectives in Sports Science that are also reflected in policy. Numerous scholars have pointed out that

healthy lifestyles are not equally accessible to all, and health maintenance in old age is not always a matter of making the 'right' choices, especially when taking into account the potential impact that inequalities experienced across the life course have in later life (Katz & Calasanti, 2015; Martinson & Berridge, 2015); therefore, 'ageing successfully' is an unobtainable goal for some. Furthermore, because of the overwhelming evidence that participation in regular physical activity ~~PA~~ is beneficial for older adults, it is often assumed that the benefits of participation in physical activity ~~PA~~ should be self-evident, and that increasing activity is just a matter of 'getting the message across' or 'getting the packaging (or physical activity~~PA~~) right.' This consumer-logic, in which physical activity ~~PA~~ is 'sold' to inactive individuals as a lifestyle choice via EIC programmes, is based upon a flawed assumption that knowledge and information alone can drive behaviour, and that short-term behaviour change naturally leads to long-term lifestyle change. It is also often assumed that participant response to an intervention can be predicted and will be rational, or can be generalised to a wider population (Kelly & Barker, 2016). In many cases, however, participant responses to an intervention are nuanced and change across a life course, such that long-term changes in lifestyle are harder to maintain.

2.3 Promoting Physical Activity in Late Life: Technology Integration

Interactive systems have the potential to address a number of the challenges associated with encouraging older people to 'get active'. Products which are easily accessible and inexpensive hold the promise of reducing public expenditure, and considerable investment has been made in the development of digital resources aimed at supporting older people to become or remain physical active, with the aim of increasing healthy years of life.

In Sports Science, technology is predominantly used in a very functional manner, often in order to set or monitor performance targets, or monitor physical progress. For example, commonly used technological solutions include use of pedometers and accelerometers to monitor ~~PA~~ frequency of physical activity, duration and intensity in combination with other motivational methods, such as physical activity ~~PA~~ consultations or prompts via mobile telephone (Bravata et al., 2007; Chen, 2005; De Cocker et al., 2008; Fitzsimons et al., 2008; King et al., 2013). Similarly, technological tools are commonly used to measure biophysical measures of performance, including for example, heart rate monitors (Meyer & Broocks, 2000; Nelson et al., 2007) and cycle ergometers (Pang et al., 2005).

Likewise, HCI research, over the past decade, has examined the potential of interactive systems to support physical activity ~~PA~~ among older adults. Moving beyond the application of commercially available systems for monitoring and tracking, researchers have developed new systems directly addressing older people as end-users (e.g., to encourage physical activity ~~PA~~ and motivate behaviour change similar to systems provided for younger audiences; Albaina et al., 2009), or to provide therapy and rehabilitation (e.g., many of the systems analysed in this paper – see Table 2). Moreover, HCI research has provided recommendations to inform the design of technology to support ~~PA~~ physical activity among older adults, exploring accessibility requirements (e.g., Gerling et al., 2012) along with preferences and values that may influence how older adults perceive technology in the context of physical activity ~~PA~~ (e.g., Fan et al., 2012). However, it remains unclear to what extent currently available systems match the needs and preferences of older adults, and how ongoing discourse on policy and ageing is reflected in technology. In particular, do researchers predominantly promote a model of 'active ageing' from a vision of older adults as individuals who

enrich society, with respect for the individual life courses of older adults, including their personal preferences, ~~yet~~ while acknowledging the socio-cultural and socio-economic forces older adults are subject to (see Figure 1). Or rather, do researchers ~~primarily~~ exclusively ~~justify~~ present their designs ~~via~~ by adopting an economic motive (i.e., a reduction of cost for overall society if older adults age 'better')?~~, and d~~And in so doing, do we~~oes this lead to the reducing~~ reduct~~io~~en of populations of older adults to a decontextualized, homogenous group of rational agents, united by decline, yet a~~t the same~~simultaneously ~~time~~ individually responsible for their (in)active lifestyles, or can both perspectives go hand in hand?

Recent discourse in the HCI community on how older adults are viewed in general (Vines et al., 2015) and how technology is designed for this group (Cozza et al., 2016) suggests similar criticisms as certain schools of thinking in sports science have raised (e.g., Phoenix & Orr, 2014), outlining ~~this~~ that deficit-focused perspectives on active ageing can lead to the design of technology that insufficiently accounts for the needs of older adults. In this review, we address the issue through examination of technical systems aiming to support physical activity~~PA~~ among older adults that were published at leading HCI venues ~~(and can therefore be regarded as flagship projects addressing this research space~~and can therefore be regarded as flagship projects addressing this research space.~~) , with the goal of understanding~~Our goals in doing so are to understand the impact that discourse on active ageing and related policy have had on the field and how motives around active ageing and economic benefit are represented in research;~~ how HCI interventions relate to those developed in sports science, and what challenges need to be addressed to deliver effective and enjoyable systems.

3. A Review of Technology to Support Physical Activity in Late Life

We present a ~~systematic review~~structured search of research in Human-Computer Interaction with a focus on older adults and physical activity~~PA~~. The core research question we address is whether and how policy on active ageing is represented in Human-Computer Interaction research, and how it affects resulting technological artefacts. In this section, we provide an outline of our methodology and describe our results.

3.1 ~~Systematic~~ Structured Retrieval of Relevant Publications

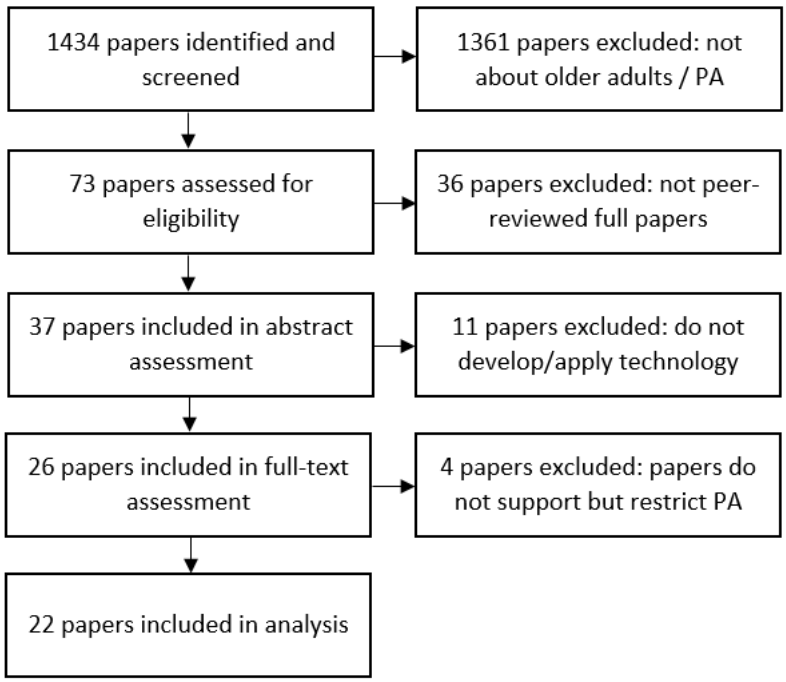
To explore how discourse on ageing affects research within HCI that addresses physical activity ~~PA~~ and older adults, we carried out a ~~systematic review~~structured search of publications between 1997 (when the idea of active ageing was first proposed) and 2017.

Our literature search was carried out in several steps. First, we identified the most cited publication venues in Human-Computer Interaction according to Google Scholar's citation indices. On this basis, we identified the top ten journals and conferences to be searched. Additionally, we included the ACM SIGACCESS Conference on Computers and Accessibility and the associated journal ACM Transactions on Accessible Computing (TACCESS) as the flagship venues of the HCI community that specifically publishes research on technology for older adults. For an overview of venues along with publications considered for and included in analysis, please see Table 1.

We carried out 12 separate searches in the respective databases only including results occurring within the specified publication (e.g., we searched the ACM Digital Library specifically for papers published at CHI) and in the given timeframe. The

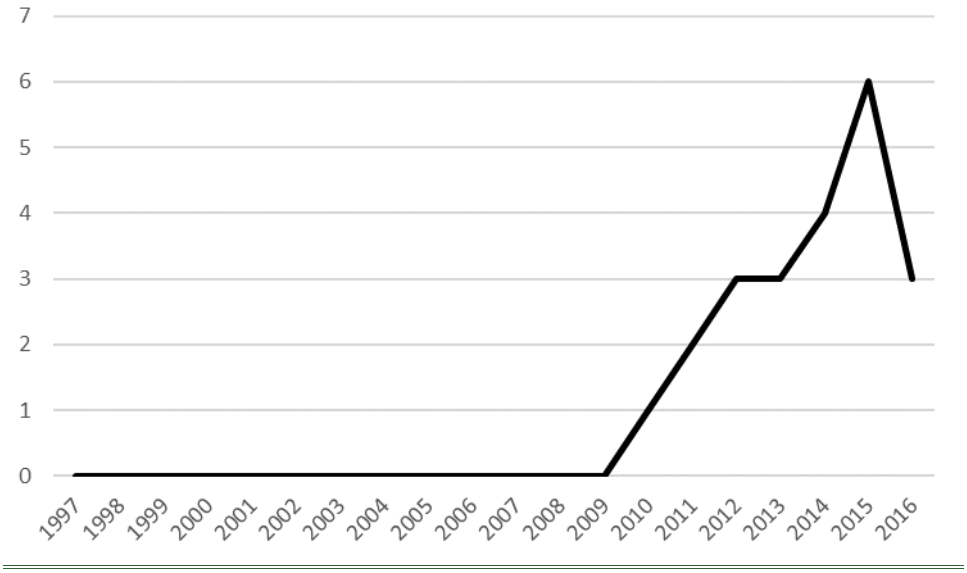
search terms applied in this first round addressed the theme of movement in the context of ageing, and included the following: *Physical activity, physical stimulation, exercise, sport, occupational therapy, physical therapy,* and *rehabilitation*. Across all venues, the initial search returned 1,434 results. We then carried out a manual search to identify papers addressing older adults, building on search terms applied by Vines et al., (2015): *ageing, aging, older people, older adults, seniors, elderly, later life, age-related, retiree, retired, elders, geriatric, life course, grandparent, grandmother, grandfather*. Manuscripts were included for further analysis if they made reference to these terms in any section of their work, excluding related literature and references, to ensure ageing was a central theme. This reduced the initially identified set of papers to 73 results. We then further screened the remaining manuscripts for quality according to reviewing process (e.g., we excluded extended abstract conference presentations) to focus on high-quality peer-reviewed content.

Figure 2. Flow of the structured search and review.



This further reduced the included papers to 37. We then thoroughly read the remaining papers to identify those that address physical activity~~PA~~, and either develop or apply technology to reach this goal. Out of the remaining 26 papers, we excluded three pieces of work that aim to restrict rather than encourage movement (reducing 'wandering' in older adults in long-term care), and a further paper that only made passing reference to older adults, but did not focus on the audience in system development. Out of the remaining 22 papers, we aggregated publications addressing the same project (Uzor et al., 2012; Uzor & Baillie, 2013; Uzor & Baillie, 2014; also Alankus et al. 2010 and 2011; Gerling et al. 2013 and 2015), resulting in 18 unique systems included in analysis.

Figure 3~~2~~. Number of papers on older adults, technology, and PA published per year between the years of 1997 and 2016.



3.2 Data Analysis

Our analysis approach applies Deductive Thematic Analysis (Fereday & Muir-

Cochrane, 2006) and was carried out following processes outlined by Braun & Clarke (2006). It addresses the overarching research question (RQ) of understanding existing perspectives on technology and physical activity ~~PA~~ among older adults within the HCI research community~~:~~. ~~We draw from criticisms of current approaches to activity interventions for older adults, and explore how these are reflected in the design of technology to motivate PA among older adults through the lens of sports science.~~

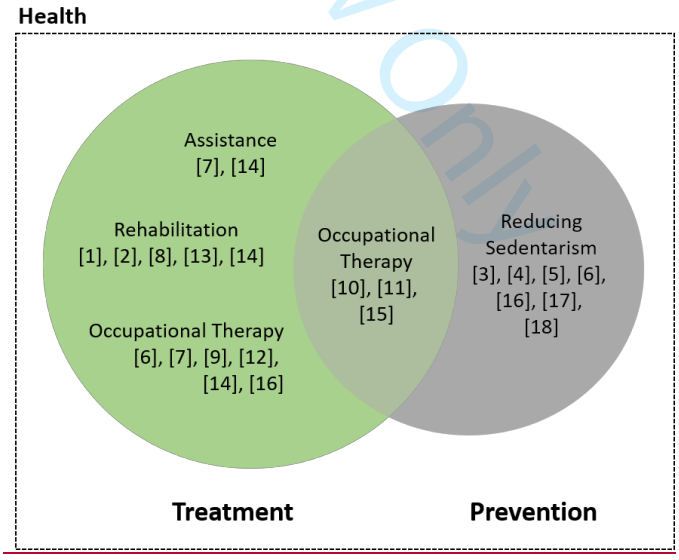
~~More specifically, o~~Our analysis is guided by two ~~further~~ key questions that emerged from our analysis of literature from Gerontology and Sport Science. ~~First, what is the prevalence of paradigms focusing on ageing as decline, emphasising deficits, burden for society along with narratives of individual responsibility to remain active? Second, how are these views reflected in technology intended to support PA?~~

W~~Hence, w~~e first focus on how research is motivated, design decisions are justified, and how findings are explained (Theme 1: Views on Older Adults Reflected in Research Design and Reporting) ~~; in this context~~and we address the presence or absence of a deficit/decline narrative of ageing. We further analyse how older adults are constructed and defined in a research context. The extent to which older people are involved in research and their views and expertise is also considered~~, along with the kind of role they are allocated, and how they are perceived as users of technology~~. Second, we investigate the dimension of technology supporting physical activity ~~PA~~ (Theme 2: Views on Older Adults Reflected in Technology Design). ~~Generally, o~~Our work builds on sports science studies that address physical activity ~~PA~~ among older adults and explores its integration with respect to agency and flexibility of use~~age~~, the setting in which the activity takes place, and specific physical activity ~~PA~~ goals it contributes to.

All papers were read and annotated by one researcher, where themes within each of the overarching categories listed above were identified. Throughout this process, a third theme was crafted, focusing on older adults' engagement and experience with technology (Theme 3). All themes were discussed and reflected upon with other members of the research team to establish robustness of results. Please note that as a result of the chosen method of analysis, findings are not broadly generalizable.

In total, 205 ~~codes were assigned to the papers that fell within these main categories~~data points were coded (we scored every paper once per code as we were interested in prevalence on a broader level rather than individual reference, e.g., if a paper made reference to age-related illness in the introduction and discussion of study participants, we only assigned one code). In the following section, we present our results and discuss them in the light of our research question.

Figure 4. Categorization of retrieved systems classified by application context (treatment / prevention) and main system goal. Systems can be scored in multiple categories; please note that all systems fall into the space of health.



To guide the reader throughout the remainder of this paper, Table 2 and Table 3 provide an overview of projects included in analysis (also see Figure 4). Table 2 offers

an overview of included systems and specifies intended target audience and system purpose to give context to some of the analysis outcomes discussed in our paper.

Table 3 provides an overview of design and evaluation approaches employed in each of the projects. We categorise projects according to their focus on end-users, and explore whether they employ user-centred design (UCD; i.e., maintain focus on user needs through methods that need not necessarily include direct user involvement) or participatory design (PD; i.e., a design approach that directly involves end-users as co-designers). We further provide an overview of evaluation approaches to support our analysis provided below.

3.3 Results

On a general level, the results reveal a strong relationship between policy on active ageing and systems developed by the HCI research community, with systems exclusively addressing physical activity among older adults in the context of health (see Figure 4). More ~~particularly~~specifically, ~~they~~ papers suggest a significant impact of a deficit-driven perspective underlying the active ageing paradigm. Here, we discuss the main themes that ~~emerged~~ were crafted during~~throughout~~ analysis: (1) Views on Older Adults Reflected in Research Design and Reporting, and (2) Views on Older Adults Reflected in Technology Design. Finally, we discuss a third theme that emerged from the interaction between (1) and (2) and that focuses on (3) Older Adults' Engagement and Experience With Technology and Physical Activity~~PA~~.

3.3.1 Views on Older Adults Reflected in Research Design and Reporting

This theme focuses on ~~the views on~~underpinning assumptions about ageing and old age which ~~older adults and aging that~~ are prominent in HCI research that explores

technology to support physical activity~~PA~~, and examines whether a deficit-focused discourse exhibited by policy on active ageing also prevails in how the HCI research community views the older person (e.g., as frail individuals for whom attenuation of age-related 'decline' is an imperative).

Goals and Motivation of Research. Deficit-focused perspectives were prevalent in the majority of projects, focusing on reducing sedentarism or treating medical conditions, reflecting the dominant approach in sports science which tends to seek 'treatment' or attenuation of age-related decline and age-related health-risk factors. In this context, only one project made explicit reference to the capabilities of older people. Hence, our results suggest that thoughts on older adults as individuals with strengths, resources, abilities and aspirations, were absent from the majority of projects.

This was also reflected by the definition of research goals, where improved functioning and the mitigation of medical issues were referred to by ~~13/18~~many projects (e.g., rehabilitation to re-gain upper limb control after stroke [1]), ~~and another 5/18~~while a smaller number of projects discussed activity-motivating technology as a means of risk-reduction in late life (e.g., reduction of falls risk [15]), with one paper explicitly mentioning the potential of movement-based technology to extend the lives of older adults otherwise under threat by sedentary behaviour [4]: *"Decreased activity adversely affects an individual's life expectancy, frequently leading to sedentary death syndrome"*. Although implicit in ~~some~~ papers which focused upon improving functional limitations, only ~~four~~ few projects explicitly commented that improved quality of life among older adults was an overarching goal of research.

Likewise, an overwhelming number of projects made reference to a deficit-focused perspective on aging,~~;~~ ~~14/18 papers made reference to~~discussing age-related changes and 'deficits',~~;~~ and ~~another 12/18 projects focused on~~ diseases associated with

later life, e.g., stroke [1, 8], dementia [6], and Parkinson's disease [7, 9]. While many papers discuss age-related changes and disability on a higher level (e.g., as part of background research), such considerations were likewise prominent in papers that give detailed insights into the backgrounds of study participants, e.g., [1] providing insights into the disabilities of older adults after stroke: *"[She] has recovered enough to be able to walk around independently, although she wears a leg brace. She has a little bit of use of her affected arm."* However, these descriptions need to be interpreted in the light of the research (e.g., design of therapeutic interventions) and the specific target audience. Here, it is important to recognize that many projects also describe abilities and successes of participants, and illustrate their backgrounds (e.g., hobbies and interests). ~~Additionally~~In this context, ~~five projects~~there were papers that explicitly commented on health economics, the lack of contribution of older people to economic wealth of society (e.g., difficulty returning to the work force [1]) and increasing financial pressures on the healthcare system (e.g., high cost of fractures as a result of falls [15]: *"The cost of fractures can be very high in most countries (estimated at $10 billion [11] in the United States and £1.8 billion in the UK)"*). In contrast, only one project ~~recognised~~ highlighted the economic strength of older adults as a customer base, suggesting that their wealth introduced significant opportunity for digital development and economic growth [10]: *"The older adult (65+) population is becoming a significant presence on the personal computer market. Senior citizens have the discretionary income, experience, interest, and free time to make use of computers in interesting ways"*.

Along similar lines, none of the projects made further reference to the strengths of older adults and positive changes that go along with late life; only one project made mention of a life-span perspective, a thought that was introduced by older adult study participants [1~~3~~]: *"[She] learned to play ping-pong as a child and recalled being a*

strong player. Despite the obvious relation to an activity that she used to enjoy, Pong was Marie's least favorite game", highlighting the importance to consider life experiences not just as a source of motivation to engage with technology and physical activity, but also as a potential barrier in this setting. Additionally, there were instances of recognizing strengths of older adults in more nuanced (however still deficit-related ways): *"[She] described taking a very aggressive approach to recovering from her stroke"*, suggesting a strong older person taking charge of their rehabilitation routines. Finally, despite the search terms not being limited to health-related settings, ~~most~~ the ~~existing~~ retrieved systems fell into this space; no system~~s~~ solely aiming to provide an enjoyable pastime for the older person were published at the included venues, an aspect explicitly challenged by critical sports science pointing out that ageing can also be regarded as a time of leisure, freedom, and pleasure, often in ways which are mutually reinforcing with wellbeing and health-related goals (e.g., Phoenix & Orr, 2014; Tulle & Phoenix, 2015).

Description of Older Adults. When analysing how older adults were portrayed, most descriptions of older people were brief, often only describing functional abilities rather than taking into account the individual and experiences across the life-span. ~~Fifteen out of 18~~Many projects focused on characteristics such as age, gender, and medical conditions resulting in disabilities relevant to the research. Only one project also reflected on the wider psychological impact of ageing whilst simultaneously taking a deficit-based approach by commenting on an individual's frustration regarding her physical impairment [1]. ~~Four out of eleven projects which~~Likewise, we came across projects that explicitly made reference to medical conditions and deficits of study participants, and applied standardised tests to evaluate prevalence and extent (e.g., applying the Mini Mental State Exam as an indicator of cognitive functioning [5, 10]).

Moving beyond ~~generalising~~ descriptions of older adults, ~~10/18 projects~~the body of papers included in the review ~~recognised~~understands heterogeneity as a core challenge throughout the research process and technology uptake. However, while there was a strong focus on heterogeneity in functional ability as an accessibility concern ~~(8/10 projects)~~, ~~whereas only 3/10 projects discussed~~ heterogeneity in terms of preferences and interests (e.g., [15] involving older adults to contribute their own ideas, and [18] discussing that elements such as exercise motivation afford different system designs) was rarely discussed.

~~Additionally~~In this context, a number of papers made detailed reference to older adults' characteristics, to be considered in the research process. The most prominent themes that ~~emerged~~ were crafted throughout analysis focused on difficulties and risks, i.e., issues around non-compliance, and vulnerability of older adults as a result of age-related changes. With regards to 'non-compliance' (i.e., whether older people were compliant or non-compliant with exercise regimes – an interesting perspective in itself), ~~3/18~~some projects commented on the older person not adhering to activity routines without exploration of underlying reasons that might extend beyond a lack of motivation; ~~one project (~~[18]~~)~~ however did explore reasons for sedentarism beyond motivation, also exploring barriers such as winter weather conditions and the general living environment. Additionally,~~, one project~~ [5] raised concerns around social dynamics that might introduce difficulties when deploying technology in a group setting. Adopting a different perspective, ~~a subset of three papers~~ some research teams addressed issues surrounding vulnerability that can be exposed through engagement with technology, e.g., drawing attention to age-related changes due to the physical nature of interaction paradigms [5] and emphasizing disease progression [9]. These projects suggest that vulnerable groups of older adults ~~sometimes~~ in some instances

need protection in the context of technology design and deployment. In contrast, ~~one~~ another project also discussed the role of older adults as customers, adopting a perspective that puts the older person into a role that implies agency rather than protection or guidance, and that opens up an opportunity to integrate perspectives that emphasize agency, leisure and pleasure in late life; factors which have been shown to be key considerations in much gerontological and sports science literature (e.g. Phoenix and Tulle 2015; Phoenix and Grant 2009).

Involvement of Older Adults in Research Process. We examined the degree of involvement of older adults in the research process to understand to which extent their views were invited throughout system development, suggesting a perspective that emphasizes the importance of the involvement of older adults in the design of physical activity~~PA~~, rather than seeing them as passive recipients of physical activity programmes who need to be 'convinced' to become physically active (e.g., see Kelly & Barker, 2016).

In terms of system design, ~~a vast majority of~~many projects ~~(16/18)~~ adopted a user-centred design approach that considered the needs of older adults at early stages of the development process. While not all projects directly involved older adults as active research participants in the design stages, efforts were made to adopt their perspective through literature analysis (e.g., [5]) or the application of personas (e.g., [14, 15]), and through the involvement of experts such as therapists and carers (e.g., [6]). Only ~~two projects~~ [9] and~~,~~ [15] followed a fundamentally participatory design approach in the initial stages, directly involving older adults as co-designers. Particularly regarding [15], older adults were included as design partners and made detailed suggestions and created entire concepts that they would like to engage with. However, in the course of the research it remains unclear whether participant-suggested solutions were implemented,

as those prominently presented as part of the follow-up papers represented solutions suggested by the research team.

~~Almost all projects (16/18) directly involved~~Involvement of older adults as study participants was widespread but varied in ~~to varying~~ extent~~s~~, e.g., through long-term field research (e.g., in care facilities [4, 6] and home-based research such as [15]), evaluations in clinical settings (e.g., 13), or participation in lab studies (e.g., [9, 11]). Despite working on technology that the authors considered useful for older adults, ~~two further~~ a small number of projects did not include older adults at the evaluation stage, working with young adults and therapists instead [12, 14]. Generally, shorter-term evaluation approaches of technology were prevalent; existing research gives little insight into the long-term uptake of technology interventions to support physical activity~~PA~~ among older adults, leaving HCI-based research into activity interventions open to similar criticisms as EICs in sports science, where interventions are insufficiently evaluated regarding their long-term uptake and benefit.

3.3.2 Views on Older Adults Reflected in Technology Design

To further explore views of HCI research on older adults, examination of resulting systems was a key element of our analysis.

Interestingly, regarding the type of systems, ~~with 9/18 systems,~~ a large share of projects implemented game-based solutions, and two systems applied gaming technologies; these approaches hold the promise of offering a 'motivational pull' (see Ryan et al., 2006) that can be leveraged to engage individuals in otherwise unattractive activity. However, to date it remains unclear whether playful approaches are a motivator or barrier for older adults to engage in physical activity; the general approach~~This~~ echoes the behaviourist-drive in mainstream sports science about the need to simply 'convince' older adults to engage in physical activity~~PA~~. ~~Two f~~Further projects are

varied, focusing on ~~developed~~ autonomous systems, ~~three projects explored~~ the potential of wearables for older adults, and one project offered a video conferencing solution. In terms of system design, all projects made executive decisions on the type of system to be developed, and did not involve older people at this stage of the design process, suggesting a largely prescriptive approach.

Regarding project goals, most~~12/18~~ systems had an application context within the space of rehabilitation and occupational therapy, for example, addressing upper limb rehabilitation after stroke [1], preventative measures to reduce the risk of falls [5], or supporting older people living with Parkinson's disease [9, 7]. Additionally, ~~seven~~ a group of projects focused on the reduction of sedentarism and physical stimulation rather than addressing specific therapeutic goals. Likewise, ~~another three~~there are projects that focus on self-monitoring and change of general behaviour and healthcare-relevant aspects of life. This demonstrates an overwhelmingly functional approach with all projects addressing disease- or otherwise health-related aspects associated with physical activity~~PA.~~: ~~For example,o there~~ ur search did not return a single~~was no~~ system with a primary focus on enjoyment or skill development in a leisurely context, systems which are well researched for younger audiences (e.g., Mueller et al.'s (2003) extensive work on augmented sports) .

In terms of delivery of physical activity~~PA~~, we analysed setting and nature of activities provided by the systems along with the flexibility they offer end-users. Regarding the setting, most systems~~14/18~~ were intended for home-based use or use in care or healthcare-related facilities. Only ~~4/18~~a small number of systems could also be used away from home (wearable systems with a focus on tracking [8] and assistance [7]). Additionally, there were differences in the social nature of the application context, with ~~12/18~~most systems being designed for individual use, and ~~3/18~~a small number of

systems inviting participation of two or more older adults, for example, in co-located group activity [5] or remote participation of multiple users [13]. In this context, ~~only 2/18~~a small number of systems were designed to flexibly accommodate individual or multi-user participation depending on the preference and further requirements of end-users. Further investigating the way physical activity ~~PA~~ was integrated, only ~~one out of 18 systems~~ [3] offered older adults flexibility regarding the kind of activities they would like to carry out, despite the recognised need for flexibility in active ageing provision (Foster and Walker 2015). The vast majority ~~(16/18)~~ of systems integrated ~~PA~~ physical activity in a way that was mostly prescriptive, giving detailed instruction regarding the kinds of movements to be carried out that would also define the overall nature of the activity (e.g., most of the game-based solutions required specific player movements for game input). While some systems integrated calibration routines to adapt movements to individual factors (e.g., player range of motion in [11]), these elements were either carried out together with therapists, or system-sided and determined through algorithms, leaving little room for agency among end-users to individually adapt movement routines to their preferences or daily abilities. This aspect was picked up by older adult participants rather than researchers of one of the projects [5] in which older adults engaged with the initially proposed game-based solution, but then moved on to explore commercially available products in accordance with their preferences.

3.3.3 Older Adults' Emergent Interaction and Experience With Technology and Physical Activity

This final theme brings together the previously discussed topics, focusing on the experience that emerges from older adults' interaction with physical activity ~~PA~~ focused technology. In particular, there was a strong focus on usability and user experience across all projects, analysis revealed discussion of aspects relating to user engagement

and technology acceptance, and there was reflection on challenge, goal-setting, and goal-tracking in the context of technology, physical activity~~PA~~, and older people.

Generally, all projects reflected on the experience that older users would have with the system, with a prevalence of perspectives addressing issues related to accessibility and usability. Moving beyond these basic requirements, a number of projects also explored whether enjoyment emerged throughout interaction; however, while part of many evaluations, this aspect was only central to few, and often discussed retrospectively, e.g., [1] commenting that they "*have not fully explored how to ensure that [older adults] will find the games motivating*". Along these lines, hardware design and overall system appearance in the living space of the older person were only discussed by one project [13] with regards to hedonic aspects, and one other project [18] specifically designed activity visualisations to be aesthetically pleasing. In stark contrast, another project [3] received user feedback suggesting one of the proposed wearable solutions resembled a dog collar: *"The opinions for the device attached to the neck were controversial. Some of them claimed its image was easy to be associated with negative objects such as a dog collar."*~~,~~ This outlines~~outlining~~ the need for designers to reflect upon the look and feel of resulting technology as a means of positively engaging end-users, and taking these concerns seriously should they arise.~~.~~

This leads to a further sub-theme of user engagement with technology to support physical activity ~~PA~~ along with issues surrounding technology acceptance. Generally, few projects explored the integration of technology as a self-directed activity (e.g., [3] proposing the use of wearables to allow older adults to independently monitor their own health), while many others – particularly those with an application purpose in therapy and rehabilitation - focused on either prescribed frequency and duration of engagement (e.g., [15]) or supervision by therapists. In terms of non-engagement, only ~~four~~ few

projects discuss this case with the desire to understand older adults' motives, in contrast, ~~5/18~~ other projects take a technology acceptance perspective where acceptance is the ultimate goal and concerns are not followed up on, e.g., one project pointing out that some older adults were sceptical of game-based occupational therapy, but not offering any explanation, and [10] explicitly commenting that *"[older adults] initial rejection will be reduced"* if they engage with the system often enough.

Finally, the last sub-theme that emerged focused on older adults' perspectives on challenge, goal-setting, and goal-tracking within technology to support physical activity~~PA~~, suggesting conflicting perspectives depending on end-user preferences. Particularly regarding challenge and goal-setting (e.g., level of difficulty in game-based interventions), some projects reported participant perspectives that suggest a risk of vulnerability if skills and abilities are not well-matched with system requirements. Likewise, older adults involved in [66] strongly felt that they would not like to be 'tracked' by the system, ensuring that progress is experienced individually but not quantified through the system~~–~~. In contrast, a number of projects commented on the potential of tracking and scoring to provide feedback and increase engagement, e.g., [5] discussing the value of 'adequate' challenge, [2] commenting on benefits of goal-setting and –tracking, and [1] outlining the potential that tracking could have for review by healthcare professionals.

4. Discussion

This paper presents a summary of research published at key venues for Human-Computer Interaction that addresses physical activity among older adults through the design of technical interventions. Our analysis reveals that policy on active ageing and its interpretation have trickled down into research in Human-Computer Interaction, impacting the motivation of research, the purpose of developed systems, and

perspectives on older adults involved in the research process and beyond. This is reflected the design of technologies which resemble functionalist systems, which reduce the user to a PA-related need, ability or capacity without taking into account other personal needs and preferences. These findings are in line with previous discourse analysis of general HCI research addressing older adults by Vines et al. (2015) who are critical of the strong emphasis on deficit-driven research, and reflect findings in the field of Ubiquitous Computing reported by Cozza et al. (2017) who further highlight that older adults' meaningful involvement in technology research remains low.

4.1 Critical Reflection on Physical Activity, Late Life, and the Role of Technology

Research in HCI cites contemporary policy on active ageing with a dominant focus on deficit perspectives on the process of ageing as a key motivator for its research, and the strong focus of currently available systems on biomedical problems underlines this notion. While these findings need to be interpreted in the light of the employed search terms that also included disease-related keywords such as occupational therapy and rehabilitation, the overwhelming absence of systems designed to support physical activity ~~PA~~ in leisurely settings that should nevertheless have been retrieved through the inclusion of keywords such as physical activity and exercise is surprising. However, this finding is in line with sports science, where the notion that 'exercise is medicine' has become commonplace (e.g. Sallis, 2009), particularly for 'at risk' groups such as older adults. From a critical perspective, whilst arguing that biomedicine has produced much valuable information about the physical and cognitive-psychological effects of ageing on the physically active body, Phoenix and Grant (2009) have also argued a need to understand the subjective experiences of meanings attached to physical activity during later life. Such an approach would illuminate the complexities of ageing and physical

activity~~PA~~, including individual identity, life experience, individual beliefs and values and the impact of the environment, elements which are currently under-researched by the HCI community. For example, a shift away from the use of technology to primarily prescribe and monitor activity levels amongst older people, constructed as passive recipients of physically activity programmes, to create systems that emphasize agency and diversity in activity would seem to offer significant potential to overcome these problems, and empower older participants. Likewise, Phoenix and Orr (2014) highlight that pleasure is a driving factor for older adults to remain physically active throughout late life; exploring how to support this aspect through technology is something that the HCI research community has successfully achieved for younger audiences (e.g., Mueller et al., 2003), and should also seek to provide for activities enjoyed by older persons, viewing them as active consumers rather than passive recipients of technology-based interventions (also see Cozza et al., 2017).

4.2 Reflecting on Core Challenges for Technology to Support Physical Activity to Put Older Adults at the Heart of the Research Process

As a result of the impact of policy on active ageing in HCI, the core challenges for the HCI research community developing technology to support physical activity ~~PA~~ among older adults are broadly similar to those faced within sports science: the creation of enjoyable, empowering leisure experiences that effectively motivate physical activity ~~PA~~ in a positive setting, while also being aware of individual differences between older adults, acknowledging their socio-cultural context, their preferences, and health. Here, we focus on four main aspects that were particularly prevalent in our analysis that offer opportunity for the HCI community to re-focus on the needs and preferences of older adults, and put them at the heart of the research process.

4.2.1 Challenge 1: Communicating agency through choice instead of creating prescriptive interventions

Our review shows that HCI research often makes a priori decisions on the technology that will be used to support physical activity ~~PA~~ among older adults, as well as the integration of physical activity ~~PA~~ routines, leaving little room for older adults to voice their preferences, or to adapt physical activity ~~PA~~ to individual situations. This reduces agency of the older person, and may introduce additional barriers to physical activity ~~PA~~ rather than acting as a facilitator. For example, many projects included in this review presented older adults with games or gaming technology. However, there was little reflection on the appeal that games would have to older adults, and there were several instances in which games were chosen not because they would particularly appeal to older players, but because gameplay could easily be mapped onto pre-existing movement patterns. As a result, many of the systems still remained prescriptive and predetermined. While this may represent a requirement for systems to support therapy and rehabilitation,(e.g. Evans & Crust, 2015; Wheatley, 2005), it also bears the risk of carrying over challenges related to low patient engagement.

Pathways to solution. To address this challenge, future research in HCI should reflect on the choice of technology and possibly involve end-users in the decision-making process at early stages. Exploring technologies that would allow a more flexible integration of physical activity ~~PA~~ would give the older person a say in the nature of their engagement. It would also challenge the tendency to use technology in an objectifying, instrumental way (usually by experts) in exercise and physical activity~~PA~~. Offering technological solutions that older adults can use and understand without the need for expert intervention or interpretation would offer significant potential to empower older adults to make choices on their own terms. Likewise, the topic of non-

engagement with technology (also see Waycott et al., 2015) is one that warrants further discussion in the context of older adults, physical activity~~PA~~, and technology. In terms of emphasizing agency and empowering older adults to take ownership of physical activity~~PA~~, we need to be open to end-users who decide not to engage with systems in certain situations, carefully explore their reasons for doing so, and also accept that technology may not be the answer for every older person wishing to remain physically active or engage in physical therapy. Free choice is central.

4.2.2 Challenge 2: Reconciling participatory design and design by proxy

Our analysis revealed that most projects adopted a user-centred design that moved beyond the use of surrogates reported by Cozza et al. (2017). However, only a small number of projects directly involved older adults through the practice of co-design. Instead, many papers reported the involvement of therapists or carers in lieu of the older person. While their perspective is certainly helpful and relevant in the context of systems to support therapy and rehabilitation, or when designing for groups of end-users with limited ability to express their needs and desires, designing by proxy – asking other stakeholders to represent the interests of the intended group of end-users – bears the risk of systematically misrepresenting the interests of older people.

Pathways to solution. In the future, HCI research should further address the challenge of balancing the needs of all stakeholders, while maintaining a strong perspective on not only needs but also preferences of older people as end-users of technology. Where possible, one way of addressing this issue would be the further exploration and adaptation of interdisciplinary and participatory design approaches, directly involving older adults not only in the evaluation but also in the design of technology. This is in line with recent developments in Gerontology that emphasize the importance of involvement of older people throughout the research as co-researchers

(e.g., Ward & Barnes, 2016), outlining the potentially transformative powers of co-creation (Buffel, 2015).

4.2.3 Challenge 3: Building on strengths and offering challenge, but being mindful of vulnerability

As suggested by research included in our review, creating systems that adequately challenge older adults offers the opportunity of enabling them to build skill in an empowering way, and is in line with views that emphasize the importance of later life as a time when health and wellbeing can become intertwined with leisure, new challenges and growth (e.g., see Gard et al., 2016; Katz & Calasanti, 2015). However, this may increase the risk of vulnerability for certain end-users, for example, if exercises are too difficult or therapeutic goals are overly ambitious. It has been widely recognised that care, and possible medical advice, is often necessary amongst newly active participants (Bangsbo et al 2019). This suggests that a more nuanced approach is necessary to understanding the needs of older people in the context of technology design.

Pathways to solution. To adequately address user needs, there is an opportunity in ability-based design that focuses on strengths of users (also see Wobbrock et al., 2011); this could be coupled with adaptive systems that dynamically adjust difficulty of activity to user performance (an approach commonly applied in games; Hunicke, 2005). Beyond better accommodating a broad range of users, this approach offers potential for compassionate design, for example, by dynamically adapting to daily performance of vulnerable users. Further, it would generally facilitate a positive user experience that emphasises competence through a good fit between user ability and challenge provided. In this context, psychological models taking into account the life span of older adults (e.g., Baltes & Baltes, 1993) could support the development of more nuanced technology that is attuned to the needs of the individual, also drawing attention to the

abilities of older adults (which is in line with the idea of ability-based design in HCI). ~~[]~~ Likewise, Gerontological and social-scientific perspectives encourage us to not only view aging as decline but also as a time of growth (e.g., Bauer & Park, 2010, Phoenix ~~and~~ & Orr, 2014), which offers an interesting lens for HCI research.

4.2.4 Challenge 4: Combining functionalism and hedonism, and designing to improve quality of life

The final challenge is the tension that exists between functionalism and hedonism. While the accessibility community has previously highlighted the importance of older adults' values when creating technology to support physical activity~~PA~~ (Fan et al., 2012), only two systems made reference to the importance of hedonism. Ideas around the wider appeal of technology (e.g., in terms of visual presentation or technical devices used) were widely absent from the remaining projects. In this context, it is important to recognize the importance of functionalist perspectives to ensure basic suitability of technology, but also be mindful of the challenges this approach might create throughout the research process, possibly introducing a dehumanizing focus on abilities and physical functioning.

Pathways to solution. To address this challenge, the HCI research community needs to embrace functionalism and hedonism as equally important aspects of technology design for older adults, and leave room for the enjoyment and fun that older adults may have when engaging with technology and in physical activity~~PA~~. To this end, Gerontology can offer valuable insights into the importance of hedonism as a means of engaging and empowering older people. For example, work by Liddle and colleagues (2013) demonstrates that purpose and pleasure found through participation in art and crafts-related activities also improves health outcomes despite primarily focusing on the activity itself, whilst Phoenix and Orr (2014) emphasise the possibility

for pleasurable experiences when being physically active. This suggests that priorities in the design of technology to support physical activity ~~PA~~ in late life need to be reconsidered, first raising questions around pleasure that can be achieved through technology-supported physical activity~~PA~~, and focusing on functional outcomes afterwards, a trend also reflected in broader discourse on technology and older adults (Vines et al., 2015) along with wider societal debate on quality of life in late life.

5. ~~Conclusion~~Limitations and Future Work

The work presented in this paper ~~needs to~~should be viewed in the light of a number of limitations that are important to consider when interpreting our findings. Most importantly, our search only included the most cited HCI outlets, omitting regional venues such as NordiCHI and specialized conferences such as CHI PLAY that might have yielded additional results. Readers therefore ~~need to be careful~~should take care to understand our results as an enquiry into the dominant discourse at major HCI venues, whereas smaller or more focused research communities m~~ight~~ay ~~be~~ currently adopt~~ing~~ a different narrative. Likewise, our work follows a qualitative rather than a quantitative approach, and findings need to be interpreted under consideration of the limitations of the qualitative research paradigm, i.e., accepting that results are intertwined with the experience of researchers, and that findings do not generalize in the same way as those of large-scale quantitative research (Myers, 2000; Braun & Clarke, 2006). Generally, we see scope for future work to carry out a comprehensive systematic review to explore whether the findings presented here also apply to the wider HCI research community, focusing on quantitative rather than qualitative aspects of the work that is carried out to address physical activity among older adults.

6. Conclusion

HCI researchers recognise the potential that technology has to support physical activity ~~PA~~ among older adults, but ~~are~~ the dominant discourse at major HCI venues is largely driven by contemporary policy that adopts a deficit-based perspective on ageing, while simultaneously promoting ideas on active ageing that put potentially harmful pressure on the individual to live up to notions of successful activity. Moving beyond functionalist approaches to technology design offers the opportunity of creating systems that recognise these risks. Researchers should leverage the full opportunity that technology has to contribute to the lives of older people when reflecting their values, embracing needs and preferences not only in terms of physical health, but with a broader view on the emphasis of agency, enjoyment, and overall well-being in late life.

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Table 1. Publications considered in analysis in descending order of recognition based on h5-index.

Publication name	**Papers on PA (PA & Older Adults)**	**Papers included**
ACM SIGACCESS Conference on Computers and Accessibility	23 (8)	3
ACM Transactions on Accessible Computing (TACCESS)	18 (2)	2
ACM SIGCHI Conference on Human Factors in Computing Systems (CHI)	408 (16)	13
ACM Conference on Computer-Supported Cooperative Work & Social Computing (CSCW)	42 (2)	0
ACM Symposium on User Interface Software and Technology (UIST)	23 (0)	0
ACM Conference on Pervasive and Ubiquitous Computing (UbiComp)	89 (1)	0
IEEE Transactions on Affective Computing	17 (0)	0
ACM/IEEE International Conference on Human Robot Interaction (HRI)	52 (2)	1
International Journal of Human-Computer Studies	369 (2)	0
Mobile HCI	35 (2)	1
ACM Transactions on Computer-Human Interaction (TOCHI)	15 (0)	0
Behaviour & Information Technology	343 (6)	2
Overall	**1,434 (41)**	**22**

Table 2. Categorization and description of included systems along with reference to intended target audience as identified within the paper and overarching purpose of the system.

Authors	**Category**	**Description**	**Target Audience**	**Purpose**
Alankus et al. 2010, 2011 [1]	Game	Custom-designed motion-based game; camera-based and accelerometer-based movement tracking	People who had a stroke, Older Adults in particular	Rehabilitation
Ayoade & Baillie 2014 [2]	Interactive system	Stationary interactive system; accelerometer-based movement tracking for in-home knee rehabilitation	People undergoing knee replacement surgery including older people	Rehabilitation
Fan et al. 2012 [18]	Visualisation	System that visualizes tracked activity in artistic way (combined with Fitbit wearable)	Older adults	Reducing sedentarism
Fang & Chang 2016 [3]	Wearables	System to facilitate health monitoring; neck-worn, arm-worn and wrist-worn options	Healthy and chronically ill older people	Health monitoring, Reducing sedentarism
Gerling et al. 2012 [4]	Game	Custom-designed motion-based game; camera-based movement tracking	Institutionalised older adults	Reducing Sedentarism
Gerling et al. 2013,	Game	Custom-designed motion-based	Older adults who	Reducing

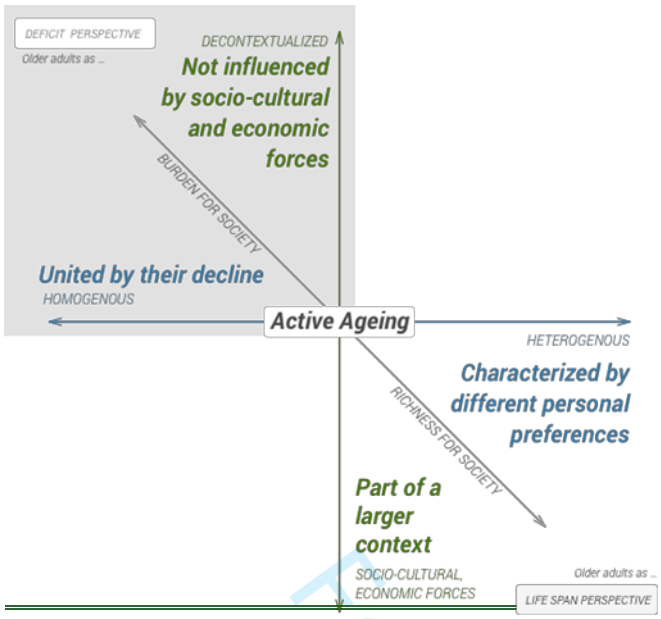
2015 [17]		game; camera-based movement tracking	use wheelchairs	sedentarism
Gerling et al. 2015 [5]	Game	Custom-designed motion-based game and commercially available games; camera-based movement tracking	Older adults in independent living settings and institutionalized older adults	Reducing sedentarism
Hebesberger et al. 2016 [6]	Robotic	Robotic walking companion for group-use in long-term care	Institutionalized older adults with dementia	Occupational therapy, Reducing sedentarism
Mazilu et al. 2014 [7]	Wearables	System to support training instruction and auditory assistance for freezing episodes in Parkinson's patients	People with Parkinson's including older people	Occupational therapy, assistance
Micallef et al. 2016 [8]	Mobile app	Application on phone/tablet/watch to deliver exercise reminders for post-stroke upper limb rehabilitation	People who had a stroke including older people	Rehabilitation
McNaney et al. 2015 [9]	Game	Custom-designed motion-based game to support people with Parkinson's; camera-based movement tracking	Older people with Parkinson's	Occupational Therapy
Sáenz-de-Urturi et al. 2015 [10]	Game	Custom-designed motion-based game; camera-based movement tracking	Older adults with and without age-related impairment	Occupational Therapy
Smeddinck et al. 2013 [16]	Game	Custom-designed motion-based game; camera-based movement tracking	Older adults with and without age-related impairment	Reducing sedentarism, Occupational Therapy
Smeddinck et al. 2015 [11]	Game	Custom-designed motion-based games; camera-based movement tracking	Anyone including older adults	Occupational Therapy
Tang et al. 2015 [12]	Interactive system	System to provide in-home therapy; on-screen instruction and feedback; camera-based movement tracking	People with joint and muscle injury including older people	Occupational therapy
Taylor et al. 2011 [13]	Video conferencing tool	Video conferencing system to connect people with COPD and therapists for group-based in-home rehabilitation	People with COPD including older people	Rehabilitation
Threatt et al. 2014 [14]	Robotic	Autonomous table to support upper-limb rehabilitation (among other purposes)	People who struggle to live independently including older people	Rehabilitation Occupational Therapy Assistance
Uzor and Baillie 2012, 2013, 2014 [15]	Game	Custom-designed motion-based games for falls prevention; accelerometer-based movement tracking	Older adults, people who have had a fall and those at risk	Occupational Therapy

Table 3. Overview of design and evaluation approaches employed by projects included in analysis.

Authors	**Design approach**	**Evaluation approach**
Alankus et al. 2010, 2011 [1]	User-Centred Design with therapists, some user participation and iterative	Qualitative short-term study, location unclear; 4 women who had a stroke

	adaption	
Ayoade & Baillie 2014 [2]	User-Centred Design with therapists and former patients	Quantitative long-term study (six weeks), field research at hospital and participants' homes; 15 patients undergoing knee surgery, age-range 47-85 (Med=70)
Fan et al. 2012 [18]	User-Centred Design with older adults	Qualitative medium-term study (3 weeks); three physically active older adults, age range 58-71.
Fang & Chang 2016 [3]	Unclear – no hints at UCD or PD	Quantitative short-term study, field research; 24 participants aged 50+ (54% aged 65+)
Gerling et al. 2012 [4]	User-Centred Design with therapist and based on literature	Quantitative short-term study at long-term care facility; 12 older adults, age range 60-90 (M=76.7, SD=10.6)
Gerling et al. 2013, 2015 [17]	User-Centered Design based on literature	Quantitative short-term study at care home and senior residence; 8 older adults who regularly use wheelchairs, average age 75 (SD=5.53).
Gerling et al. 2015 [5]	User-Centred Design based on literature	Qualitative long-term study (3 months) at care home and senior residence; 16 older adults, average age 73.5 (SD=4.18) at CH, 79.9 (4.8) at SR
Hebesberger et al. 2016 [6]	User-Centred Design with therapists	Mixed-method long-term study at care home; number of older adults with dementia involved unclear
Mazilu et al. 2014 [7]	User-Centred Design with clinicians, engineers, and patients	Quantitative medium-term study (one week) at a hospital; 5 people with Parkinson's, average age 75.5 (SD=4.7)
Micallef et al. 2016 [8]	User-Centred Design with therapists, health professionals, and prospective end-users	Quantitative home-based medium-term study (three days); 15 people who had a stroke, age range 36-74
McNaney et al. 2015 [9]	Participatory Design with therapists and patients; invisible design	Qualitative lab-based medium-term study (two sessions); 8 people with Parkinson's, age range 48-78
Sáenz-de-Urturi et al. 2015 [10]	User-Centred Design with therapists	Quantitative short-term study at care home; 14 older adults (3 people with MCI); age range 65-94 (M=89, SD=8.94)
Smeddinck et al. 2013 [16]	User-Centred Design based on literature and with therapists	Quantitative lab-based short-term study; 15 older adults; age range 61-85 (M=73.6, SD=7.77)
Smeddinck et al. 2015 [11]	User-Centred Design with therapists	Mixed-method long-term study (5 weeks) at outpatient practice; 29 patients with chronic spine problems, average age 66 (1st Qu=59, 3rd Qu=73)
Tang et al. 2015 [12]	User-Centred Design with therapists	Quantitative lab-based short-term study; 16 graduate students
Taylor et al. 2011 [13]	Participatory Design with clinicians and patients	Mixed-methods home-based long-term study (8 weeks); 4 people with COPD aged 65-79
Threatt et al. 2014 [14]	User-Centred Design with therapists	Quantitative lab-based short-term study; 11 healthcare experts
Uzor and Baillie 2012, 2013, 2014 [15]	Participatory Design with older adults (2012)	Mixed-method short-term study (2013), 11 older adults aged 68-79; mixed-method long-term study (12 weeks; 2014), 17 older adults, average age 75.5

~~Figure 1. Illustration of the different possible perspectives and dimensions of the 'Active Ageing' model.~~



~~Figure 2. Number of papers on older adults, technology, and PA published per year between the years of 1997 and 2016.~~